

Run-11 RHIC Polarimetry Analysis

version 0.3

I. Alekseev, E. Aschenauer, G. Atoyán, A. Bazilevsky, A. Dion, H. Huang,
Y. Makdisi, A. Poblaguev, W. Schmidke, D. Smirnov, D. Svirida, and A. Zelenski

November 3, 2011

Abstract

We present results on the measurement of polarization of proton beams in RHIC run 11.

Contents

1	Beam polarization	3
1.1	Beam polarization in a fill	3
2	Systematic Uncertainties	4
2.1	Uncertainties on p-Carbon polarization	4
2.2	Uncertainties on beam polarization in a fill	7
2.3	Uncertainties on beam polarization in collisions	9
2.4	Uncertainty on single spin asymmetry	9
2.5	Uncertainty on double spin asymmetry	9

1 Beam polarization

In the 2011 run every attempt was made to collect good data with all RHIC polarimeters in every fill. As the result of this effort, in most of the 2011 fills we have several measurements of the beam polarization $P_{\text{crb}}^{(\text{p})}$ (from context, $\text{p} = \text{B1U, Y1D, B2D, Y2U}$; $\text{p} = \text{U, D}$; or $\text{p} = \text{B, Y}$) obtained with the p-Carbon polarimeters and the average fill polarization, P_{jet} , obtained with the H-jet polarimeter. Most of the p-Carbon measurements were “sweep” measurements thus providing us with corresponding horizontal $R_v^{(\text{p})}$ and vertical $R_h^{(\text{p})}$ beam profiles. From the “sweep” measurements we calculate the fill average polarization¹ $\overline{P_{\text{crb}}^{(\text{p})}}$ with the corresponding statistical error $\Delta\overline{P_{\text{crb}}^{(\text{p})}}$, and the fill average polarization profiles $\overline{R_v^{(\text{p})}}$ and $\overline{R_h^{(\text{p})}}$ for each p-Carbon polarimeter.

The absolute H-jet polarimeter provides a direct measurement of the beam polarization P_{jet} whereas the polarization $P_{\text{crb}}^{(\text{p})}$ is initially calculated using predictions for the p-Carbon analyzing power based on the 2004 run data [?]. We choose not to rely on these estimates but instead we correct on average the p-Carbon numbers to the H-jet value in each fill. The normalization factor $k_{\text{jet/crb}}^{(\text{p})}$ is defined by the average ratio over all fills as:

$$k_{\text{jet/crb}}^{(\text{p})} = \left\langle \frac{P_{\text{jet}}}{\overline{P_{\text{crb}}^{(\text{p})}}} \right\rangle_{\text{fills}}. \quad (1)$$

It will be shown later that the normalization to the H-jet value can also account for some systematic effects associated with the measurement by the p-Carbon polarimeters while still allowing one to benefit from the larger statistics. We calculate the correction factors for each of the p-Carbon polarimeters individually. Formally, the corection for the central value and the statistica error can be written as:

$$\overline{P^{(\text{p})}} \equiv \overline{P_{\text{crb}}^{(\text{p})}} \times k_{\text{jet/crb}}^{(\text{p})} \quad \text{and} \quad \Delta\overline{P^{(\text{p})}} \equiv \Delta\overline{P_{\text{crb}}^{(\text{p})}} \times k_{\text{jet/crb}}^{(\text{p})} \quad (2)$$

1.1 Beam polarization in a fill

In general, we do not see a reason for using measurements from either upstream or downstream polarimeter alone. Therefore, we calculate the final fill polarization, \overline{P} , for each beam by calculating the weighted average of the two p-Carbon polarimeters in the ring:

$$\overline{P} = \frac{\sum_{\text{p}=\text{U,D}} \overline{P^{(\text{p})}} w^{(\text{p})}}{\sum_{\text{p}=\text{U,D}} w^{(\text{p})}} \quad \text{and} \quad (\Delta\overline{P})^2 = \sum_{\text{p1,p2}=\text{U,D}} w^{(\text{p1})} w^{(\text{p2})} V_{(\text{p1p2})}, \quad (3)$$

where the weights $w^{(\text{p})}$ are defined through a covariance matrix V as:

$$w^{(\text{p})} = \frac{\sum_{\text{p1}=\text{U,D}} (V^{-1})_{(\text{p1p})}}{\sum_{\text{p1,p2}=\text{U,D}} (V^{-1})_{(\text{p1p2})}} \quad (4)$$

In case of uncorrelated errors on $\overline{P^{(\text{U})}}$ and $\overline{P^{(\text{D})}}$ the covariance matrix is diagonal with $V_{(\text{pp})} = (\Delta\overline{P^{(\text{p})}})^2$ and weights $w^{(\text{p})} = 1/(\Delta\overline{P^{(\text{p})}})^2$.

¹The better way is to calculate a luminosity weighted average.

The physicists analyzing the data from the collider experiments STAR and PHENIX are interested in the beam polarization in collisions. This polarization takes into account the intensity profile of the both beams:

$$\overline{P}_{\text{coll}} = \frac{\iint \overline{P}(x, y) I^{(\text{B})}(x, y) I^{(\text{Y})}(x, y) dx dy}{\iint I^{(\text{B})}(x, y) I^{(\text{Y})}(x, y) dx dy} \quad (5)$$

Assuming the polarization and intensity profiles have a gaussian shape the relation between \overline{P} and $\overline{P}_{\text{coll}}$ can be simply written as:

$$\overline{P}_{\text{coll}} = \overline{P} \times k_{\text{coll}} \quad \text{with} \quad k_{\text{coll}} = \frac{\sqrt{1 + \overline{R}_h} \sqrt{1 + \overline{R}_v}}{\sqrt{1 + \frac{1}{2}\overline{R}_h} \sqrt{1 + \frac{1}{2}\overline{R}_v}}. \quad (6)$$

In the calculation of the profile correction factor k_{coll} we use the profile ratios \overline{R}_h and \overline{R}_v averaged over the fill. These quantities are extracted from the fit [?].

It is not uncommon for the analyzers to combine a number of fills in order to calculate the average polarization. While the statistical uncertainty is always independent in distinct measurements a special care should be taken in calculation of separate components of the total systematic uncertainty on the final average. In the following we discuss the systematic uncertainties and their correlation in details.

2 Systematic Uncertainties

In this section we discuss the systematic uncertainties associated with the polarizatin measurement by both the p-Carbon and H-jet polarimeters. Not all of the discussed uncertainties directly enter the final result as some can be indirectly accounted for through a proper normalization.

2.1 Uncertainties on p-Carbon polarization

It is clear that due to normalization of the p-Carbon fill average to the H-jet the final uncertainty on $\overline{P}^{(\text{p})}$ directly depends on the precision of the H-jet measurement itself. We distinguish the following three sources of systematics associated with the measurement by the H-jet polarimeter.

Normalization to H-jet (accuracy) As an estimate for this uncertainty, Δ^{norm} , we use the statistical uncertainty $\Delta k_{\text{jet/crb}}^{(\text{p})}$ on the normalization factor $k_{\text{jet/crb}}^{(\text{p})}$. It is a global uncertainty that fully correlates across individual fills. Note that for a single fill Δ^{norm} is simply equal to the statistical error on the H-jet measurement while it decreases as $\frac{1}{\sqrt{N}}$ when the number (N) of considered fills increases. The best estimate of Δ^{norm} is calculated using the set of all available fills in this run. The ratio of the H-jet to the p-Carbon values is shown in Figure 1 and the normalization factors with respect to the polarization calculated with the 2004 analyzing power are shown in Table 2.

We regard this error as correlated between the two polarimeters in each ring but uncorrelated across the yellow and blue rings. The relative uncertainties are listed in Table 3.

Normalization to H-jet (precision) As seen in Figure 1 the distribution of ratios $K \equiv P_{\text{jet}}/\overline{P}_{\text{crb}}^{(\text{p})}$ by fill significantly deviates from a constant for all four polarimeters (although Y2U has the least significant disagreement). We attribute this inconsistency, σ^{norm} , to systematic effects seen in the p-Carbon polarimeters. Specifically, an essentially unknown orientation of the target to the proton

Table 1: Normalization factors with respect to the measurements utilizing the 2004 run predictions.

	$k_{\text{jet/crb}}^{(\text{p})} \pm \Delta k_{\text{jet/crb}}^{(\text{p})}$
B1U	$(0.998 \pm 0.011 \times 0.936) = 0.934$
Y2U	$(1.000 \pm 0.011 \times 0.933) = 0.933$
B2D	$(1.027 \pm 0.013 \times 1.030) = 1.058$
Y1D	$(1.005 \pm 0.015 \times 0.904) = 0.909$

beam in each measurement can lead to variations in carbon energy losses in the target. Another contribution perhaps comes from a nonuniform motion of the target through the beam. We assume that the nature and the scale of such systematic effects do not vary significantly from fill to fill and thus, we can estimate the overall systematic contribution by solving the following equation for σ^{norm} .

$$\frac{1}{N} \sum_{i=\text{fills}} \frac{(K_i - k_{\text{jet/crb}}^{(\text{p})})^2}{(\sigma_{K_i}^2 + (\sigma^{\text{norm}})^2)} = 1 \quad (7)$$

We regard this error as uncorrelated across the polarimeters and individual measurements. The common relative uncertainties for all fills are listed in Table 3.

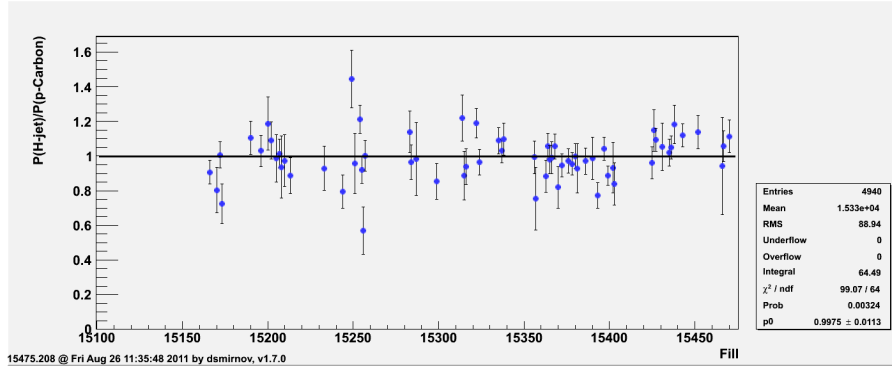
H-jet molecular background The average polarization values P_{jet} rely on the hydrogen jet target polarization as measured by a Breit-Rabi polarimeter. Prior to the 2011 run the jet target was believed to be contaminated with unpolarized molecular hydrogen H_2 . In fact, a special study was carried out in 2004 to estimate the H_2 background in the hydrogen target [?]. The study has shown a contribuion of $\sim 3.7\%$ from H_2 lowering the typical polarization numbers of the H-target from $\sim 96\%$ to $\sim 92\%$. The total relative error associated with this measurement was estimated to be 2%. The latter directly propagates to the final polarization results via the correction of P_{jet} for the H_2 background.

In this run we observe that the total background to the H-jet can be significantly polarized thus the assumption that the molecular hydrogen is unpolarized is questionable. In the current analysis we use the uncorrected value of $\sim 96\%$ for the jet target polarization, however, we decided to keep the previously obtained $\Delta_{\text{jet}}^{\text{mol}} = 2\%$ for the 250 GeV proton beams.

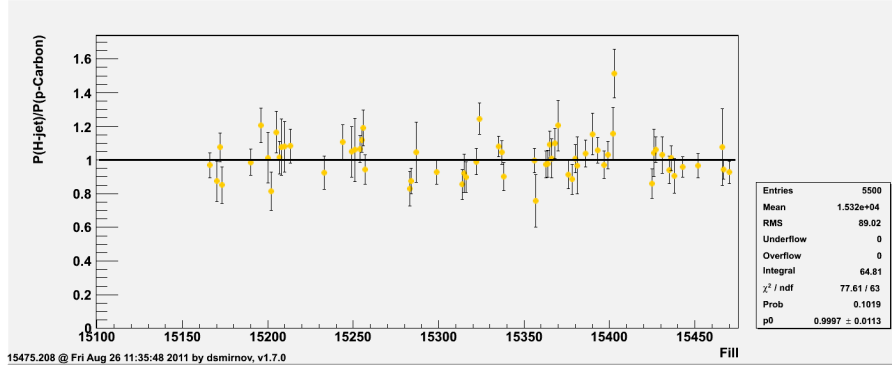
We regard this error as correlated between the yellow and blue beams and all four p-Carbon polarimeters. The relative uncertainties for all fills are listed in Table 3.

Total H-jet background The error $\Delta_{\text{jet}}^{\text{bkg}}$ represents the uncertainty on the total estimated background in the measurement of P_{jet} . While the major contributor is believed to be the H_2 in the target some other sources can contribute to the total background. For example, we do not know how much inelastic processes can contribute to our final sample. Also, since the H-jet measures polarization of the two beams simultaneously, one can imagine that there is a non-zero contribution from the back scattering from one beam contaminating the other. The background is estimated using the method of side bands in which the total count in the non-signal strips is extrapolated to the signal ones. We do not have an estimate of this unceratainty in 2011 (???), instead we use the value of 3% as was defined in the previous run.

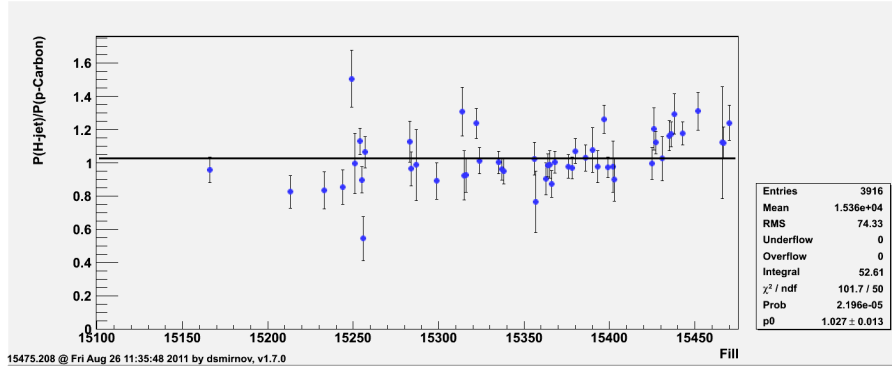
We regard this error as correlated between the yellow and blue beams and all four p-Carbon polarimeters. The relative uncertainties for all fills are listed in Table 3.



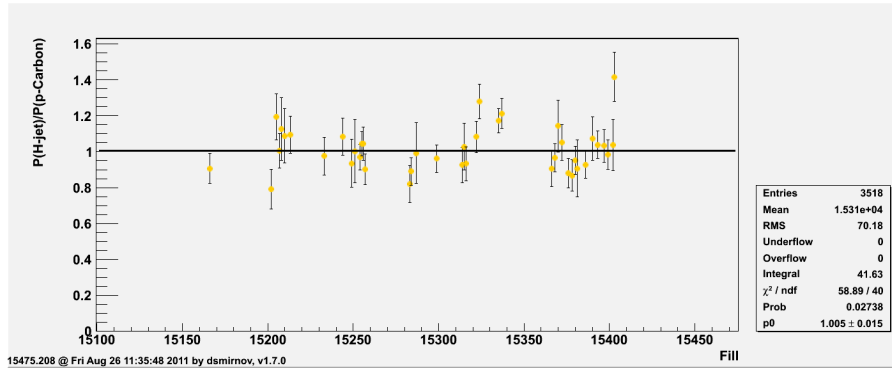
(a) Blue-1 Upstream



(b) Yellow-2 Upstream



(c) Blue-2 Downstream



(d) Yellow-1 Downstream

Figure 1: The ratio of P_{jet} and $\overline{P_{\text{crb}}^{(p)}}$.

Polarization profile In the 2011 run we also observe a systematic shift in the central polarization values as determined directly from a standard sweep measurement and a corresponding value extracted from the polarization *vs.* intensity fit. The bias is believed to be caused by the fact that the target does not exactly follow the uniform motion of the frame when crossing the beam. Instead, the target may be electrostatically attracted to the beam center causing an incorrect weighting of the collected events. We believe that the polarization extracted from the fit represents a more accurate estimate of the true beam polarization. To account for this inconsistency we introduce a scale factor $k_{\text{prfl/swp}}^{(\text{p})}$ defined as

$$k_{\text{prfl/swp}}^{(\text{p})} = \left\langle \frac{\overline{\mathcal{P}_{\text{crb}}^{(\text{p})}}}{\overline{P_{\text{crb}}^{(\text{p})}}} \right\rangle_{\text{fills}}, \quad (8)$$

where $\overline{\mathcal{P}_{\text{crb}}^{(\text{p})}}$ is the polarization extracted from the polarization *vs.* intensity fit.

Table 2: Normalization factors for the sweep measurements.

	$k_{\text{prfl/swp}}^{(\text{p})} \pm \Delta k_{\text{prfl/swp}}^{(\text{p})}$
B1U	0.9739 ± 0.0015
Y2U	0.9761 ± 0.0013
B2D	0.9859 ± 0.0017
Y1D	0.9863 ± 0.0013

We regard this error as uncorrelated across the polarimeters and individual measurements. The common relative uncertainties for all fills are listed in Table 3.

Summary The total uncertainty $\Delta \overline{P^{(\text{p})}}$ on $\overline{P^{(\text{p})}}$ is:

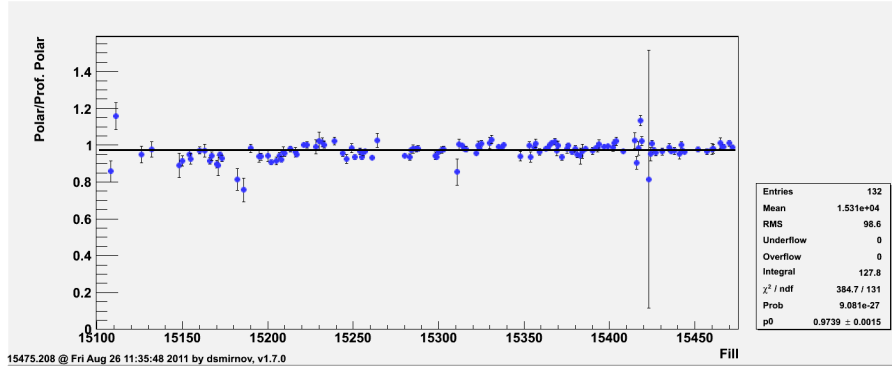
$$\Delta = \Delta_{\text{stat}} \oplus \Delta^{\text{norm}} \oplus \sigma^{\text{norm}} \oplus \Delta_{\text{jet}}^{\text{mol}} \oplus \Delta_{\text{jet}}^{\text{bkg}} \quad (9)$$

Table 3: Summary of the relative systematic uncertainties for the p-Carbon polarimeters.

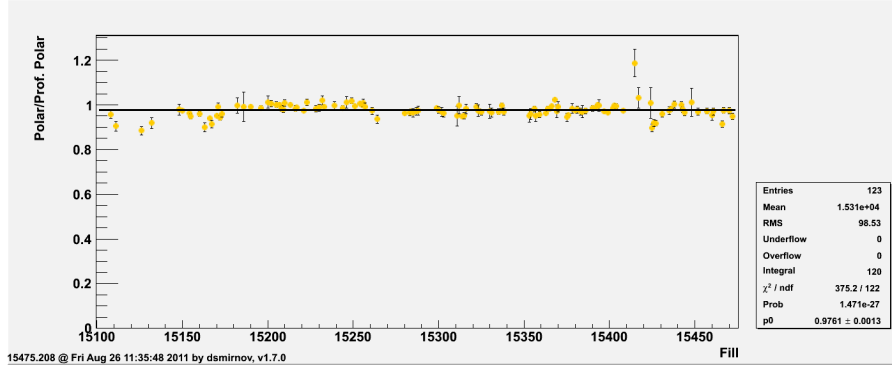
	B1U	Y2U	B2D	Y1D
$\Delta^{\text{norm}}, \%$	1.1	1.1	1.2	1.5
$\sigma^{\text{norm}}, \%$	7.0	5.4	10.1	6.3
$\Delta_{\text{jet}}^{\text{mol}}, \%$	2.0	2.0	2.0	2.0
$\Delta_{\text{jet}}^{\text{bkg}}, \%$	3.0	3.0	3.0	3.0
$\Delta^{\text{prfl}}, \%$	0.2	0.1	0.2	0.1
$\sigma^{\text{prfl}}, \%$	2.9	2.2	1.9	3.5

2.2 Uncertainties on beam polarization in a fill

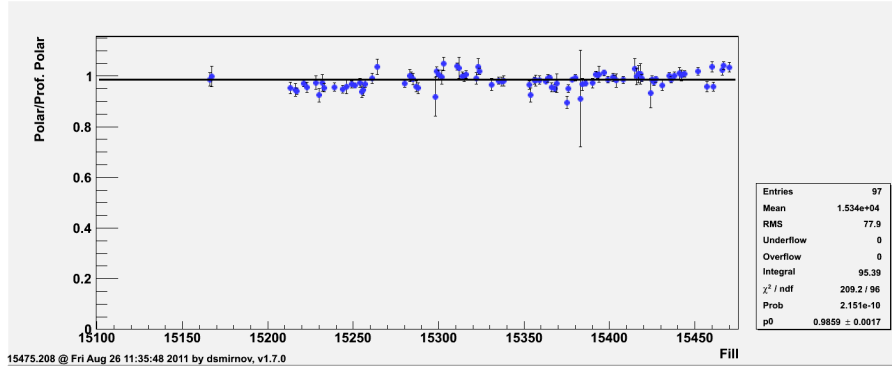
Upstream vs downstream polarimeter In the fills where measurements from the two polarimeters in the same ring are available we observe non-statistical variations in the measurements even when they closely follow each other in time. At the moment, the observed fluctuations cannot be associated with a single source or a known difference in the devices therefore, we assign a



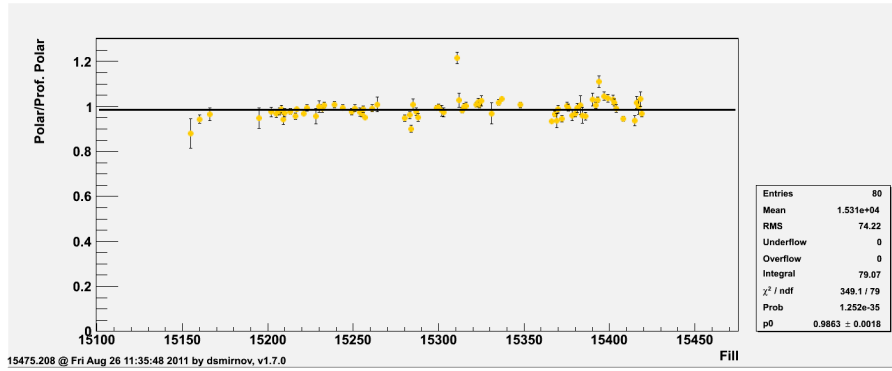
(a) Blue-1 Upstream



(b) Yellow-2 Upstream



(c) Blue-2 Downstream



(d) Yellow-1 Downstream

Figure 2: The ratio of $\overline{\mathcal{P}_{\text{crb}}^{(p)}}$ and $\overline{P_{\text{crb}}^{(p)}}$.

systematic error, $\Delta^{\text{U vs D}}$, on the fill average. We estimate the systematic uncertainty of this kind by calculating the difference between the fill average as measured by the two polarimeters. From Figure ?? the average difference is XXX. In order to cover most of our measurements we conservatively assign $\Delta^{\text{U vs D}} = XXX$.

We regard this error as uncorrelated between the yellow and blue beams.

2.3 Uncertainties on beam polarization in collisions

We define error Δ^{R} as an error on the average fill polarization in collisions $\overline{P}_{\text{coll}}$. This is not a systematic error but rather a propagation of the statistical errors on the measured quantities \overline{R}_h and \overline{R}_v according to equations (6). As one can see on Figure ?? the statistical errors on \overline{R}_h and \overline{R}_v are quite large and systematic effects are not clearly visible as they must be on the same or smaller level as statistical fluctuations. For now we use the statistical error as the total uncertainty on \overline{R}_h and \overline{R}_v leaving the estimation of the systematic effects for the future analysis. We regard this error as uncorrelated between the yellow and blue beams.

Summary For the sources of systematic uncertainties discussed above the total errors on the average fill polarization can be written as:

$$\Delta \overline{P} = \Delta_{\text{stat}} \overline{P} \oplus \overline{P} \times \Delta^{\text{U vs D}} \quad (10)$$

$$\Delta \overline{P}_{\text{coll}} = \Delta_{\text{stat}} \overline{P}_{\text{coll}} \oplus \overline{P}_{\text{coll}} \times (\Delta^{\text{U vs D}} \oplus \Delta^{\text{R}}) \quad (11)$$

and for the average over a subset of selected fills we have:

$$\Delta \langle \overline{P} \rangle_{\text{fills}} = \langle \Delta \overline{P} \rangle_{\text{fills}} \oplus \langle \overline{P} \rangle_{\text{fills}} \times (\Delta^{\text{norm}} \oplus \Delta_{\text{jet}}^{\text{mol}} \oplus \Delta_{\text{jet}}^{\text{bkg}}) \quad (12)$$

$$\Delta \langle \overline{P}_{\text{coll}} \rangle_{\text{fills}} = \langle \Delta \overline{P}_{\text{coll}} \rangle_{\text{fills}} \oplus \langle \overline{P}_{\text{coll}} \rangle_{\text{fills}} \times (\Delta^{\text{norm}} \oplus \Delta_{\text{jet}}^{\text{mol}} \oplus \Delta_{\text{jet}}^{\text{bkg}}) \quad (13)$$

2.4 Uncertainty on single spin asymmetry

For measurements of the single spin asymmetry the experiments use the average of the two beam polarizations $\frac{\langle P^{(\text{B})} \rangle + \langle P^{(\text{Y})} \rangle}{2}$. The total uncertainty is then calculated using the values in Table ?? for different beams. Taking into account the proper correlation between the two beams we obtain:

$$\Delta = \frac{1}{2} \times (\Delta^{\text{norm}})^{(\text{B})} \oplus (\Delta^{\text{norm}})^{(\text{Y})} \oplus \left((\Delta_{\text{jet}}^{\text{mol}})^{(\text{B})} + (\Delta_{\text{jet}}^{\text{mol}})^{(\text{Y})} \right) \oplus \left((\Delta_{\text{jet}}^{\text{bkg}})^{(\text{B})} + (\Delta_{\text{jet}}^{\text{bkg}})^{(\text{Y})} \right) \quad (14)$$

2.5 Uncertainty on double spin asymmetry

Similarly, the double spin asymmetry measurements use the product of two beam polarization $\langle P^{(\text{B})} \rangle \times \langle P^{(\text{Y})} \rangle$. The total uncertainty in this case is:

$$\Delta = (\Delta^{\text{norm}})^{(\text{B})} \oplus (\Delta^{\text{norm}})^{(\text{Y})} \oplus \left((\Delta_{\text{jet}}^{\text{mol}})^{(\text{B})} + (\Delta_{\text{jet}}^{\text{mol}})^{(\text{Y})} \right) \oplus \left((\Delta_{\text{jet}}^{\text{bkg}})^{(\text{B})} + (\Delta_{\text{jet}}^{\text{bkg}})^{(\text{Y})} \right) \quad (15)$$